Indian J. Phys. **73A** (1), 25–36 (1999)

IJP A
— an international journal

Searches for new particles at Tevatron

Naba K Mondal
Tata Institute of Fundamental Research, Homi Bhabha Road,
Mumbai-400 005, India

Abstract : We report on searches for a wide variety of new particles conducted recently at Tevatron collider with the DØ and CDF detectors. These include searches for Supersymmetric particles, neutral scalar particles, excited quarks, particles from a fourth generations and heavy gauge bosons.

Keywords : Supersymmetry, R-parity, Tevatron

PACS Nos. : 14.70.Pw, 14.80.Ly

1. Searches for supersymmetry

Supersymmetry relates bosons to fermions, and its existence as a good symmetry at a high mass scale requires the existence of a set of particles which are partners of their Standard Model counterparts, with the same couplings but with different spin and R-parity. (R-parity is a new multiplicative quantum number assigned so that the particles of the Standard Model have R-parity = +1, while their supersymmetric partners have R-parity = −1). The breaking of supersymmetry at a scale below the unification scale implies that the masses of the superpartners will be different (presumably, higher) than those of ordinary particles. All the supersymmetry searches reported to date from the Tevatron assume R-parity conservation, which implies that the SUSY particles are produced in pairs, and decay in cascades which must terminate in two LSP's (LSP = lightest supersymmetric particle). In most of the searches, a SUSY model is chosen in which the LSP is the lightest neutralino state $\tilde{Z}_1$. The LSP is constrained to be neutral and non-interacting, so it produces a missing transverse energy ($\not{E}_T$) signature in the detectors. The exact particle composition of the decay channels, and hence the branching fractions into various final state topologies, are very dependent on the details of the SUSY model. In calculating acceptance for the various final states, the experiments generally choose simplifying assumptions to limit the model space covered. The top squarks—the supersymmetric partners of the top quark—are a special case for SUSY searches. The large mass of the top quark has the effect in SUSY models of producing different Yukawa couplings for the top squarks which result in a pair of mass eigenstates $\tilde{t}_1, \tilde{t}_2$, the lighter of which can in fact be lighter than the top quark itself. The decays of the $\tilde{t}_1$ would be top-like, either to $W + b + LSP$ or to $\tilde{W}_1 + b$, *unless* these are not kinematically allowed. There is a region in the $m_{\tilde{t}_1}$ *vs* m_{LSP} plane, for $\tilde{t}_1$ lighter than $\tilde{W}_1$, where the only allowed decay is $\tilde{t}_1 \to c + LSP$, making searches simple and model-independent (although not easy).

We now turn to the specific SUSY searches which have been reported to date from the Tevatron. There are searches for squarks and gluinos, for charginos and neutralinos, and for the lightest top squark.

(A) Squarks and gluinos searches :

Squarks and gluinos can be strongly pair-produced at the Tevatron collider, with cross sections for $\tilde{q} - \bar{\tilde{q}}, \tilde{g} - \tilde{g}$, and $\tilde{q} - \tilde{g}$ determined in standard QCD calculations, depending on the masses of the new particles. We expect the final states to consist of either multijets $+ \not{E}_T$ or jets + leptons $+\not{E}_T$. The $\not{E}_T$ would be due to the existence of two relatively massive LSPs in the final state. Four searches for such pair production have been completed. Both DØ [1] and CDF [2] have searched for the multijet $+\not{E}_T$ final state, and the contours from these searches are shown in Figure 1. Both these searches use only the data from the 1992–93

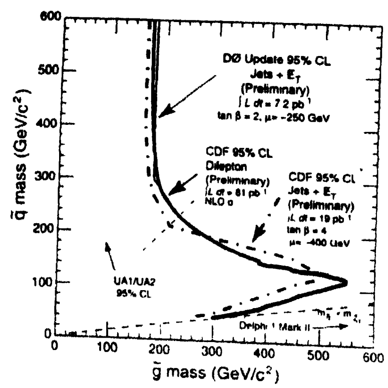

Figure 1. The 95% CL limits in the $\tilde{q} - \tilde{g}$ mass plane from three searches at CDF and DØ.

Tevatron run, and also use a leading order cross section calculation. Also shown in that figure in the contour from a search by CDF [3] for dileptons + jets $+\not{E}_T$, using the 1992–1995 data, and using an NLO cross section calculation [4] which is ≈ 20 % larger than the LO cross sections. The reach achieved in the dilepton search, with the more favourable cross section and larger luminosity, is comparable to the reach in the hadronic channel over the range where the $\tilde{q}$ mass is larger than the $\tilde{g}$ mass.

(B) SUGRA motivated search in the dielectron channel :

DØ has recently reported a new search for SUSY particles [5] within the SUGRA-GUT framework [6], which has only five free parameters : a common SUSY-breaking scalar mass (m_0), a common gaugino mass ($m_{1/2}$), a common value for all trilinear coupling (A_0), the ratio of the vacuum expectation values of the two Higgs fields ($\tan\beta$) and the sign of μ, where μ is the Higgsino mass mixing parameter. In the early searches for squarks and gluinos, probing the low mass region, one assumed a one step decay of squarks and gluinos into quark jets and LSPs. For higher mass squarks and gluinos, there are additional decay channels through chargino and neutralino intermediate states. In addition to hadronic decays, these charginos and higher mass neutralinos can also decay leptonically. In fact, in certain regions of the SUGRA parameter space, there can be substantial enhancement of their leptonic decay branching fractions. The final states in such decays contain leptons in addition to jets and $\not{E}_T$. Leptonic SUSY searches, using isolated leptons, jets and $\not{E}_T$ therefore compliment the canonical SUSY searches which look only for the jets and $\not{E}_T$.

Events for this analysis are selected by requiring at least two electrons with $E_T > 15$ GeV within $|\eta| < 2.5$ satisfying electron identification cuts, two jets with $E_T > 20$ GeV and $|\eta| < 2.5$ satisfying jet quality cuts and $\not{E}_T > 25$ GeV. In addition, events in which the invarient mass of the two electrons lies between 79 and 103 GeV are removed as possible Z events unless the $\not{E}_T$ in such events is above 40 GeV. Only 2 events survive all the above cuts.

The backgrounds for this signature are small. They comprise top quark production and decay in the dielectron channel, Z boson production in association with jets, followed by either $Z \rightarrow ee$ or $Z \rightarrow \tau\tau \rightarrow ee\nu_e\nu_e\nu_\tau\nu_{tau}$, W boson pair production in association with jets, with both bosons decaying to electrons and b and c quark production, with the heavy quark decaying into electron. An additional instrumental background arises from the misidentification of a jet as an electron. Standard Model backgrounds were studied using a combination of Monte Carlo (for kinematic efficiencies) and data (for electron identification efficiencies). Measured cross sections were used for all background processes except W boson pair production. The instrumental background due to the misidentification of a jet as an electron was determined from single electron + jets sample. The total estimated number of background events is 3.0 ± 1.3, against two events observed in data.

Therefore, there is no evidence for the production of dielectron + dijet $+\not{E}_T$ events in the data in excess of the Standard Model prediction.

From this result, DØ obtained an exclusion region in the SUGRA parameter space, by generating signal points at various points in the 2-dimensional $m_0 - m_{1/2}$ plane using (ISAJET 7.13) [7]. The three other SUGRA parameters A_0, $\tan(\beta)$, $\text{sign}(\mu)$ were fixed at 0, 2 and negative respectively and the top mass was assumed to be 180 GeV. All sparticle (gluino, squark, chargino and neutralino) production were included in the simulated samples. The response of the DØ detector was determined using a detailed detector and trigger simulation. Signal efficiencies were estimated for all the points. Careful mapping of the ($m_{1/2}$, m_0) plane was required because of changing branching fraction to leptonic final states. Abrupt changes occur when new decay modes become kinematically allowed; for example, when $\tilde{\nu}$ becomes lighter $\tilde{Z}_2$, than the decay $\tilde{Z}_2 \rightarrow \bar{\nu}\nu$ replaces $\tilde{Z}_2 \rightarrow ee\tilde{Z}_1$ as the dominant decay mode. The MSSM, a theory with no prescribed relation between gaugino and slepton masses, gives no such behaviour unless such a mass relation is put by hand.

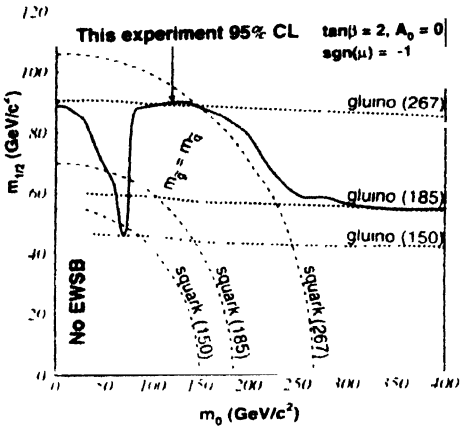

Figure 2. The exclusion contour in the m_0–$m_{1/2}$ plane with A_0, $\tan\beta$ and sgn (μ) fixed at 0, 2, and −1 respectively. The region below the solid line is excluded at 95% CL. The hatched region is where the model fails to produce electroweak symmetry breaking (EWSB). The mass contours representing the lower limits for squark and gluino masses are also shown. The masses, given in parentheses, are in GeV/c^2.

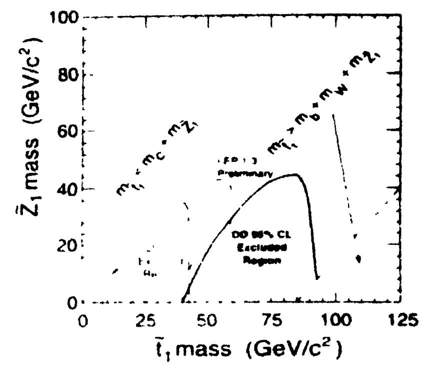

Figure 3. The 95% CL limit in the $m_{\tilde{t}_1} - m_{\rm LSP}$ plane from 1992–93 data from DØ.

Using the signal efficiencies, background expectations and the two observed events, DØ has determined the 95% CL upperlimit on the SUSY cross section, as a function of m_0 and $m_{1/2}$ using a Bayesian calculation. From these cross section limits and the leading order estimated cross sections, they determine the 95% CL exclusion contours shown in Figure 2. The excluded region is the area below the solid line. Mass contours for various squarks and gluino masses are also shown in the same figure. The "dip" in the exclusion contour is where the decay $\tilde{Z}_2 \rightarrow \bar{\nu}\nu$ becomes dominant; the rise at lower m_0 is where the decay $\tilde{Z}_2 \rightarrow \tilde{e}e$ contributes to the signal.

(C) The lightest top squark :

DØ has searched in the 1992–93 data set for the lightest top squark $\tilde{t}_1$, in the topology of two acoplanar jets $+\not{E}_T$ [8]. As mentioned above, for certain mass regions of the various SUSY particles, this channel is the only kinematically accessible one, and hence the limit is completely model-independent given only that $m_{\tilde{t}_1} < m_{W+b+\rm LSP}$ and $m_{\tilde{t}_1} < m_{\tilde{W}_1+b}$. The limit is shown in Figure 3.

(D) Search for charginos and neutralinos in the trilepton channel:

An established technique of searching for SUSY at Tevatron collider is to look for trileptonic final states from decays of the lightest chargino, $\tilde{W}_1$, and second lightest neutralino, $\tilde{Z}_2$, produced in association. Both DØ and CDF have looked for the following four trileptonic final states : [9,10] eee, eeμ, eμμ, μμμ. Here we give the details of the DØ analysis.

Various combinations of single lepton (e or μ) and dilepton triggers were used for selecting these final states. These triggers included : a single muon with $p_T^\mu > 15$ GeV/c; two muons with $p_T^\mu > 3$ GeV/c; one muon with $p_T^\mu > 8$ GeV/c plus one electromagnetic cluster with $E_T^e > 7$ GeV; one electromagnetic cluster with $\not{E}_T^e > 20$ GeV and missing transverse energy, $\not{E}_T$, > 15 GeV; and two electromagnetic clusters with $E_T^{e1} > 12$ GeV, $E_T^{e2} > 7$ GeV, and $\not{E}_T > 7$ GeV. In addition, to reduce trigger bias, during offline analysis the first or first two leading leptons (depending on trigger) are required to have their p_T at least 2 GeV above trigger threshold. For the channels involving muon, additional cuts were applied to reject back to back muons within 0.1 rad to reduce cosmic ray background and also to reject events where the $\not{E}_T$ is either back to back to the leading muon or parallel to any muon within 0.1 rad. The last cut is to reduce the effect of mismeasured muon momentum. They further required that any lepton in the event must have $E_T^e > 5$ GeV or $P_T^\mu > 5$ GeV/c. In addition, electrons and muons in these events were required to pass various quality cuts. Finally, additional decay mode specific cuts were applied to reduce the background further. For the eee channel, we rejected events having an electron pair with invariant mass between 81 and 101 GeV/c^2, or having $\not{E}_T < 15$ GeV, or having the first two leading electrons back to back within 0.2 rad. In the eμμ channel, we rejected events having two leading muons within 0.2 rad to reject J/ψ. For the μμμ channel we required $\not{E}_T > 10$ GeV and rejected events with two muon invariant mass less than 5 GeV/c^2. After applying these cuts, DØ found no events in any of the four channels.

Backgrounds were estimated from both data and MC simulations. Standard Model processes having three or more isolated charged leptons are expected to be small compared to instrumental backgrounds. The total background for all the four processes combined is 1.34 ± 0.37.

To analyze the $\tilde{W}_1 - \tilde{Z}_2$ signal characteristics, they generated Monte Carlo events for each channel and for various $\tilde{W}_1$ masses, ranging from 45 to 96 GeV/c^2 using ISAJET 7.13. These MC events follow the mass relation common to many SUGRA inspired SUSY models : $M_{\tilde{W}_1} \approx M_{\tilde{Z}_2} \approx 2M_{\tilde{Z}_1}$.

Using this, DØ presents a 95% CL upper limit on the cross section (for producing $\tilde{W}_1 - \tilde{Z}_2$ pairs) times branching fraction into any one of the trileptonic final states. Figure 4 shows the resulting limit (labelled Run 1B). Also shown in the same figure are the previously published result [11] from DØ (labelled Run 1A) and the limit based on combined (labelled Run 1A + 1B) data. Figure 5 shows the correspondiung result from the CDF experiment.

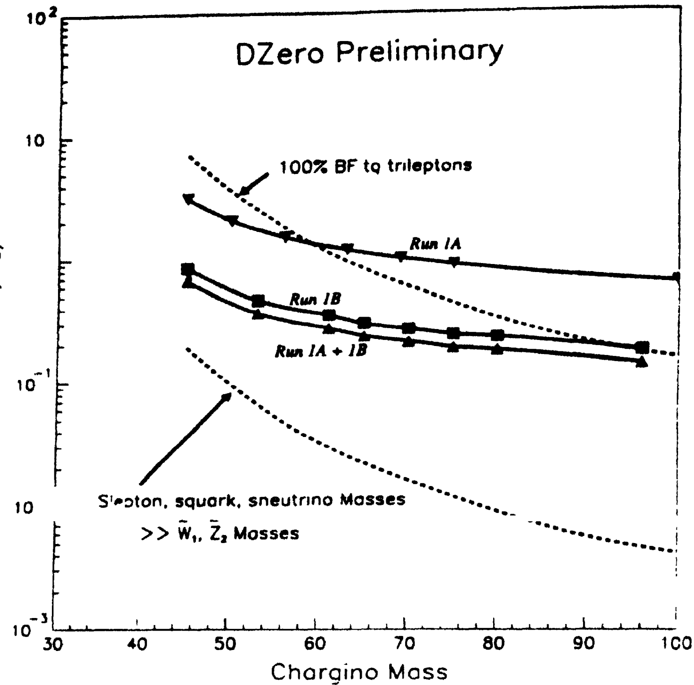

Figure 4. The 95% CL limit on cross section times branching ratio into a single trilepton channel *vs* chargino mass, from DØ trilepton search.

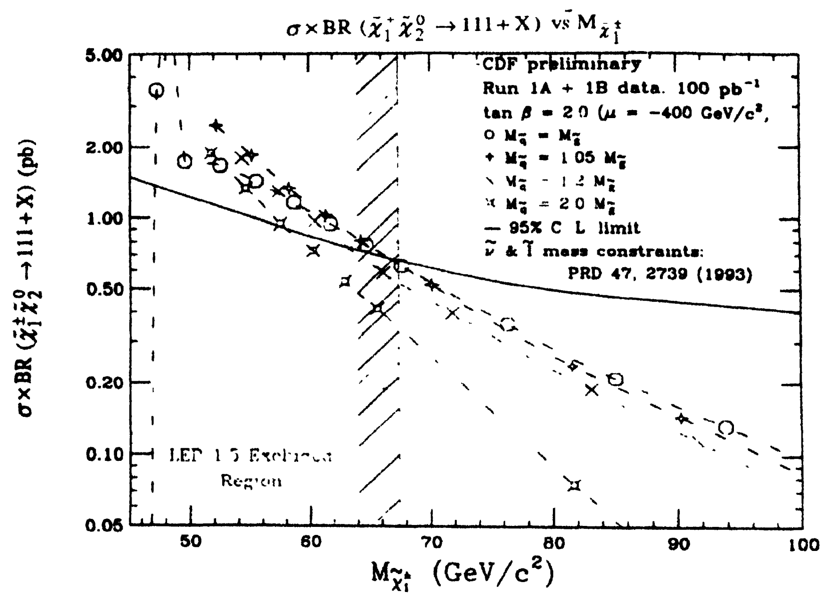

Figure 5. The 95% CL limit on cross section times branching ratio into the four trilepton channels *vs* chargino mass, from the CDF trilepton search.

2. Search for neutral scalar produced in association with W

DØ has also looked for the production of a heavy scalar particle in association with W through the process $p\bar{p} \rightarrow W + X$. This process is the feature of many models including standard model and SUSY Higgs and that of various technicolor model. Although the limits on the number of allowed signal events presented in this analysis are model independent, they derive cross section limits using acceptances derived for the case in which X has the spin and decay properties of a neutral Higgs boson decaying exclusively to $b\bar{b}$. They use events in which the W decays *via* $W \rightarrow l\bar{\nu}_l$, $l = e, \mu$ and the X decays as $X \rightarrow b\bar{b}$, where they identify b jets through the soft muon tag. The final states of such events will consist of either a high P_T electron or muon, missing transverse energy and at least two jets. The following cuts are then applied offline to select the signal. For the electron channel : (1) one isolated e with $p_T \geq 25$ GeV and $|\eta| \leq 2.5$; (2)$\not{E}_T \geq 25$ GeV; and (3) two jets with $|\eta| \leq 2.0$ and $p_T \geq 15$ GeV. For the muon channel : (1) one isolated muon with $p_T \geq 20$ GeV and $|\eta| \leq 1.7$; (2) $\not{E}_T \geq 20$ GeV; (3) two jets with $|\eta| \leq 2.0$ and $p_T \geq 15$ GeV; and (4) $P_T^W \geq 20$ GeV. They have used the complete DØ 1992–1995 data sample of 100 pb^{-1} and the number of candidate events that pass all our cuts are 12 in the electron channel and 15 in the muon channel.

The backgrounds relevant to this search are : W + jets, QCD multi-jet events in which fluctuations give rise to misidentification of jet systems as leptons and $t\bar{t}$ events. Total number of background events expected from all these sources are 15.1 ± 2.0 for the electron channel and 10.4 ± 1.4 for the muon channel. Combining the muon and electron channels they have observed 27 events in good agreement with the expected background of 25.5 ± 3.3. Based on this null result they set limits on $p\bar{p} \rightarrow W + X$ using two methods. In the first method, they estimate the signal by subtracting the background from data. In the second method, they estimate the signal by a fit to the observed dijet mass spectrum to a combination of signal and background. For the counting technique, cross section limits as a function of X mass are derived by simply computing the cross section using the following relation,

$$\sigma = \frac{N_0 - B}{AL * Br(W \rightarrow l\bar{\nu}_l)}.$$

Here N_0 is the number of events observed in the data, B the predicted background, A the detector acceptance and L is the total luminosity. The resulting 95% CL cross section limits range from 49 pb to 28 pb for masses from 80 GeV to 120 GeV respectively.

In the second technique, they have fitted the observed dijet mass spectrum to a combination of signal and background. While the background shape was obtained directly from the data, the signal shape was determined from Monte Carlo. These background and signal shapes are then used as the input spectra for a single-parameter binned maximum likelihood fit. The fit parameter is the fraction of signal events in the data. The likelihood function is

$$L = \prod_i P(N_i;\mu_i),$$

where P is the Poisson probability of finding N_i data events in the i-th mass bin, when the average expected in $\mu_i = N[f_i^B(1-\alpha)+f_i^S\alpha]$. The parameters f_i^B and f_i^S are the fraction of background and signal respectively which fall in the i-th mass bin, and α is the fraction of events in the total sample arising due to signal ($p\bar{p} \to WH^0$). N is the total number of observed events. The fractions f_i^B and f_i^S are taken from the parametrized background and signal shapes. After estimating the number of signal events as function of Higgs mass, DØ estimate the 95% CL cross section limits on the production cross section using the same technique as in the case of counting method. The corresponding 95% CL cross section limits range from 52 pb to 19 pb for X masses from 80 GeV to 120 GeV. Figure 6 shows the cross section times branching fraction limits obtained from the counting as well as shape fit analysis.

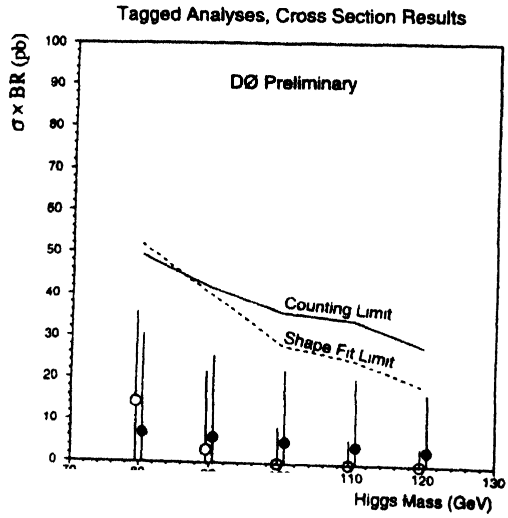

Figure 6. The 95% CL cross section limit on production of a Higgs-like resonance decaying to $b\bar{b}$, produced in association with a W boson.

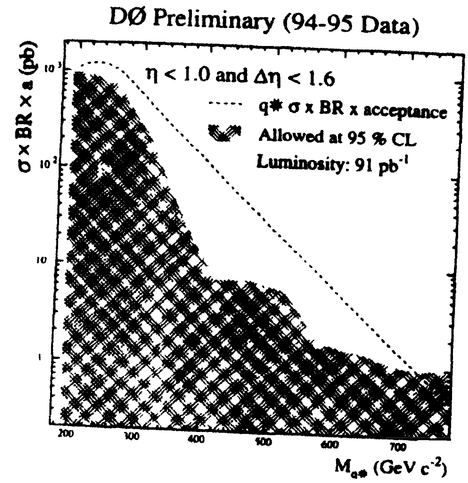

Figure 7. The 95% CL cross section limit *versus* mass for excited quarks from DØ experiment.

3. Excited quarks

Many extensions of the standard model predict new particles which decay to two jets, such as excited quarks, techni-rho's, heavy W's and heavy Z's [12–14]. The new particles would produce a resonance in the di-jet mass spectrum. DØ selects ki-jet events from approximately 91 pb^{-1} of data passing various single jet triggers with at least two jets passing the quality cuts used in the inclusive jet analysis [23]. In order to reject instrumental backgrounds, such as hot cells, cosmic rays, and energy deposits in the calorimeter from the main ring accelerator which passes through the DØ detector, they reject events with large missing transverse energy. They require the missing transverse energy be less than 70% the E_T of the leading jet. The efficiency for the data selection cuts is high. In adduition a small correction is made for the inefficiency. In order to improve signal to background, they require the two jets be in the central region of the calorimeter, $|\eta| \leq 1.0$, and that the pseudorapidity difference between the two jets be less than 1.6. The di-jet mass is calculated as $M_{jj}^2 = 2.E_{T1}.E_{T2}.(\cosh\Delta\eta - \cos\Delta\phi)$. No evidence of a resonance is seen. They interpret this null search as limits on the cross sections times branching ratio to di-jets times acceptance. They fit the spectrum to a linear combination of a NLO calculation and a excited quark line shape from the PYTHIA event generator according to a model by Baur *et al* [12] smeared with the DØ jet energy resolutions. The 95% confidence level limit as a function of mass is shown in Figure 7. The limit includes an 8% uncertainty on the luminosity and a 2% uncertainty of the efficiency of the data selection cuts. The uncertainty in the mass scale is approximately 5% and is incorporated by plotting the CL at the mass which produces the most conservative limit. The theoretical cross section from the Baur *et al* model is also shown. DØ exclude excited quarks with a mass less than 720 GeV/c^2 within this model.

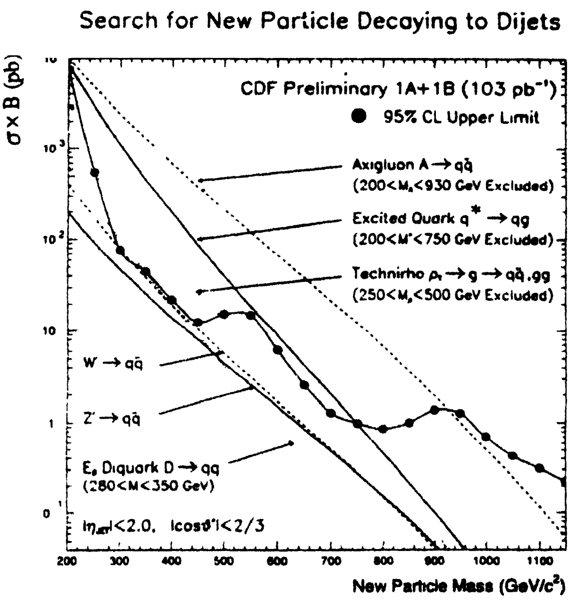

Figure 8. The 95% CL cross section times branching ratio for excited quarks, compared to the theoretical excited quark cross section and cross sections for some other new particles from the CDF dijet analysis.

In a similar analysis CDF has reported from the 1992–1995 data set a limit curve shown in Figure 8.

4. Searches for fourth generation particles

Another kind of new particle accessible at the Tevatron would be quarks and leptons from a possible fourth generation (with massive neutrinos, of course, to conform with LEP data). There are two searches for such particles presented to date, both from DØ.

(A) b' Quarks :

The charge $\frac{1}{3}$ quark of a fourth generation is required by LEP I data to be heavier than $\frac{1}{2}$ the Z^0 mass, but could possibly be lighter than the top quark. Earlier top searches [15] which did not require b-tagging of the final state would limit a b' which decayed semileptonically to charm to a mass greater than 131 GeV. However, if the CKM suppression of the decay to charm is great enough, the b' might decay wholly or in part through flavor-changing neutral current modes, for example $b + \gamma$, $b + gluon$, or $b + Z$. For the mass region between the LEP I limit and $m_Z + m_b \approx 95$ GeV, the decays to Z are forbidden and the branching ratio into $b + \gamma$ has been calculated [16]. DØ has searched for b' pair production with two possible final states : $\gamma + 3$ jets, one of which is tagged as a b jet, and $2\gamma + 2$ jets. Each search separately rules out a b' decaying *via* FCNC modes with mass between 45 and 95 GeV [17].

(B) Heavy neutrinos :

DØ [18] has also used its trielectron channel search in the 1992–93 data to set limits on a heavy neutrino that mixes with the electron neutrino, in terms of the mass and mixing parameter. The exclusion contour extends the LEP I limit to a mass of ≈ 70 GeV, for mixing parameter $(U_{e4})^2 > 0.1$.

5. Searches for heavy gauge bosons

New gauge bosons are a feature of many sorts of beyond-the-SM physics. Limits quoted here assume Standard Model couplings (and in the case of the limit for right-handed W bosons from DØ, the same CKM matrix for right and left handed states), and can be lower for different assumptions.

(A) Heavy W bosons :

A conventional search for a heavy W boson looks for extra events in the transverse mass plot above the Standard Model W. Such searches have low background and the limits are determined mostly by integrated luminosity (although they do depend on the coupling assumption, and on the assumption that the accompanying neutrino is massless). CDF and DØ report such limits [19, 20] at 650 and 610 GeV respectively.

DØ has reported two other types of search for a heavy W boson [21]. First, there is a search for evidence of a Jacobean peak in the E_T spectrum of high E_T single inclusive electron events. This search would reveal the presence of a heavy W, regardless of the handedness of the new particle, and in the limit of the massless acompanying neutrino gives a mass limit of 720 GeV for the heavy *W*-significantly higher than from either of the transverse mass searches. This limit is the solid contour shown in Figure 9. The dashed contour in that figure is obtained from a search for an explicitly right-handed *W*, decaying

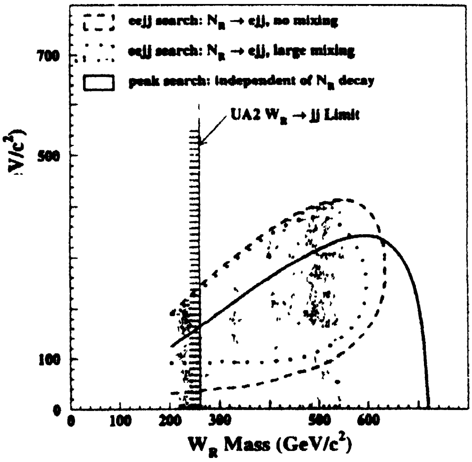

Figure 9. The limit contours from two different searches for a heavy W at DØ. See the text for a description of the searches.

to an electron plus a right-handed heavy neutrino which in turn decays to electron plus virtual *W*, giving as one final state 2 electrons + 2 jets. The lack of such events above predicted SM background is used to set a limit contour that reaches higher neutrino masses than the single electron search. This limit does depend on the right-handed model used, on the CKM matrix assumption, and on the mixing between the standard and the new state.

(B) Heavy Z bosons :

DØ and CDF have searched for evidence of a heavy Z' boson in the dilepton invariant mass spectra. The DØ limit [22] is 670 GeV, using the dielectron channel only and the 1992–95 data set. The CDF limit [19] is 690 GeV, using dielectrons and dimuons and the 1992–1995 data set. Both limits assume standard couplings for the new *Z* state.

6. Future prospects and summary

In this paper, I presented only some of the interesting results from the searches for new physics at the Tevatron. However, many other important and interesting results, like Leptoquark, Compositeness *etc* are not included due to lack of time. In addition, there is much to be done in this field. In the upcoming Run II of the Tevatron, the two collider experiments are expected to accumulate 2 fb^{-1} of integrated luminosity and thus will be able to continue searching for signatures beyond Standard Model with greater sensitivity.

Acknowledgments

I would like to thank the organisers of the 12th DAE Symposium on HEP for organising an excellent meeting and to my colleagues from DØ and CDF collaborations for providing me many useful informations. My special thanks to K Wyatt Merritt for helping me in preparing this manuscript and to D K Chaudhury for inviting me to give this talk.

References

[1] S Abachi *et al DØ Collaboration, Phys. Rev. Lett.* **75** 618 (1995); D Claes *for the DØ Collaboration, 10th Topical Workshop on Proton-Antiproton Collider Physics* eds. R Raja and J. Yoh (1995)

[2] J Hauser *for the CDF Collaboration. 10th Topical Workshop on Proton-Antiproton Collider Physics* eds. R Raja and J Yoh (1995)

[3] J Done *for the CDF Collaboration, these proceedings*

[4] W Beenakker *et al Z. Phys. C* **69** 163 (1995); W Beenakker *et al Phys. Rev. Lett.* **74** 2905 (1995)

[5] N Mondal *for the DØ Collaboration, ICHEP'96, Warsaw, Poland* (1996)

[6] S Ferrara, R Barbieri and G Savoy *Phys. Lett.* **B119** 343 (1982); S Deser and B Zurmino *Phys. Lett.* **B62** 335 (1976); P Van Nieuwenhuizen *Phys. Rep.* **117** 75 (1985)

[7] H Baer *et al Simulating Supersymmetry with Isajet 7.0/Isasusy 1.0" in Proc. Physics at Current Accelerators and Supercolliders* eds. A White and D Zeppenfeld (ANL 1993)

[8] S Abachi *et al DØ Collaboration Phys. Rev. Lett* **76** 2222 (1996)

[9] K De *for the DØ Collaboration, 11th Topical Workshop on Proton-Antiproton Collider Physics, Padova, Italy* (1996)

[10] F Abe *et al CDF Collaboration Phys. Rev. Lett.* **76** 4307 (1996)

[11] S Abachi *et al Phys. Rev. Lett.* **76** 2228 (1996)

[12] U Baur, M Spira and P M Zerwas *Phys. Rev* **D42** 815 (1990)

[13] J Bagger, C Schmidt and S King *Phys. Rev.* **D42** 815 (1990)

[14] K Lane and M V Ramana *Phys. Rev.* **D44** 2678 (1991)

[15] S Abachi DØ Collaboration *et al Phys. Rev. Lett.* **72** 2138 (1994)

[16] W S Hou and R G Stuart *Phys. Rev. Lett.* **62** 617 (1989); W S Hou and R G Stuart *Nucl. Phys* **B320** 277 (1989); P Agrawal and W S Hou *Phys. Rev* **D46** 1022 (1992)

[17] H Greenlee *for the DØ Collaboration, 11th Topical Workshop on Proton-Antiproton Collider Physics, Padova, Italy* (1996)

[18] S Abachi *et al DØ Collaboration, submitted to the XVIIth International Symposium on Lepton-Photon Interactions (LP95), Beijing, China, August 10–15* (1995)

[19] H Wenzel *for the CDF Collaboration, Fermilab-CONF-96/193-E*

[20] S Abachi *et al DØ Collaboration Phys. Rev Lett.* **74** 2632 (1995)

[21] S Abachi *et al DØ Collaboration Phys. Rev. Lett.* **76** 3271 (1996)

[22] S Abachi *et al DØ Collaboration Phys. Rev. Lett.* **74** 2632 (1995)

[23] S Abachi *et al (DØ Collaboration), FERMILAB-CONF-96/168-E*